REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
28-07-2005

2. REPORT DATE
Final

3. DATES COVERED *(From - To)*
October 2002–September 2004

4. TITLE AND SUBTITLE
Enhancement of Robotics Laboratory at
Tennessee State University

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-02-1-100

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER
03PR10720-01

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Dr. Mohan J. Malkani
Dr.Saleh Zein-Sabatto

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Tennessee State University
3500 John A. Merritt Blvd.
Nashville, TN 37209-1561

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research 342CN
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Public Availability

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Funding from 2002 DoD Infrastructure support program for HBCU/MI under BAA No. DAAD19-02-R-002 provided support for Tennessee State University to purchase five (5) ATR robots with associated laser scanners, navigation and inertial sensors, communications and speech processing tools to enhance the research capabilities of existing robotics laboratory. The impact of this equipment led to completion of 9 undergraduate senior capstone design projects and 3 masters' theses during 2002-2004. In addition undergraduate research group is formed to enrich the electrical and mechanical engineering curriculum and enhance the career opportunities of our students. The addition of new robots has enhanced our research in the area of cooperative mobile robots. The robots are able to communicate with each other and humans through wireless communication, computers and hand held devices

15. SUBJECT TERMS
Image Processing, Multiple Robot Coordination, Human Robot Interaction

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPONE NUMBER *(Include area code)*
			SAR	6	Dr. Mohan J. Malkani / (615) 963-5400

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18

TENNESSEE STATE UNIVERSITY
COLLEGE IF ENGINEERING, TECHNOLOGY AND COMPUTER SCIENCE

ENGINEERING RESEARCH INSTITUTE

FINAL TECHNICAL REPORT: ENHANCEMENT OF ROBOTICS LABORATORY

Period: 01 October, 2002 through 30 September, 2004

Submitted to Dr. Joel Davis

Program Officer, Cognitive, Neural and Social S&T Division

Office of Naval Research

(Grant # N00014-02-1-100)

By

Mohan J. Malkani, Ph.D., Director

Engineering Research Institute

College of Engineering, Technology and Computer Science

Tennessee State University

3500 John A. Merritt Boulevard

Nashville, TN 37209-1561

(615) 963-5400 Fax: (615) 963-5397

E-mail: mmalkani@tnstate.edu

July, 2005

Tennessee State University
Engineering Research Institute
College of Engineering, Technology and Computer Science

Final Report: Enhancement of Robotics Laboratory

Tennessee State University received a grant of $179,625 from the Office of Naval Research under FY 2002 DoD Infrastructure support programs for BHCU/MI BAA No: DAAD19-02-R-002. The grant provided funds to enhance the existing mobile robotics laboratory through the purchase of five All Terrain Robotic Vehicles (AVTR), which will be used indoors and outdoors. The existing B14 mobile robot at that time was about six years old and had run down its useful life. In addition the software was not current and it did not support the latest software. Other small mobile robots (Trilibots) had many on board sensors, but they had limited capability and they could not go straight and those robots including B14 could not be used outside. However, they were good for student training, but not for quality research.

It was also proposed that the acquisition of new robots would be a natural extension of research activities of the Center of Neural Networks-funded by ONR since 1992 to test, validate and develop robotics technologies in indoor and outdoor type of environments. This would expand the level of expertise of research faculty at TSU as well as help students involved in research activities to be exposed to the state-of-the-art equipment through senior capstone design projects for undergraduates and masters theses for graduate students. The research will also enrich the curriculum in appropriate courses.

It was assumed that the research activities will benefit with the acquisition of robots, and the proposed equipment will help TSU accomplish its mission and the mission of DoD to meet the intended goals and objectives by having access to the-state-of-the-art equipment and test technologies in the area of mobile robotics, distributed computing, intelligent multi-agents and sensory fusion, wireless communication and integration. It was also expected that such research activities will contribute to the advances of the literature in the areas of mobile robots and its applications in solving real-world problems in both commercial as well as government type applications.

The overall goal of the enhancement of robotics research laboratory is to conduct research in cooperative behavior of multi-agent autonomous robots. It is envisioned that a group of cooperative robots will operate in combined operator/automated or autonomous modes with sufficient intelligence to negotiate obstacles while maintaining constant line-of-sight communication with one-another in the areas of security and surveillance. Local software will provide knowledge-based feedback/recommendations on emergency operational procedures and alternatives to operators and others. Wireless communications will be implemented using advanced off-the shelf network components facilitating ease of maintenance, integration, expandability to other existing or future support systems. Robot wireless network will act as wireless outside the building for other applications and systems, such as first responder communications or tracking.

The report highlights our accomplishments in the areas of image processing, multiple robot coordination, and human-robot interaction. The report also lists the impact of robots on curriculum and minority students in science, engineering and mathematics (SEM) areas through undergraduate capstone senior design projects and masters theses completed and masters theses in progress, and the faculty publications.

Accomplishments

We have purchased three Pioneers 3-AT robots, two Pioneer 3-DX robots without internal PC, and two Pioneer 3-DX robots with internal PC. Totally we have nine (9) Pioneer mobile robots. With these robots, we have explored the following research areas:

Image Processing

Each robot is equipped with a computer vision system and we have implemented several image processing/ computer vision algorithms for robot navigation and human-robot interaction. Two different vision systems are used on the robots: Bumblebee Stereo Vision System and pan-tilt-zoom video cameras. On one Pioneer3 robot, a Bumblebee Stereo Camera Vision System is installed on a Directed Perception pan-tilt unit, as shown in Figure 1. Several software components were written for this vision system, including camera DLL (dynamic link library), pan-tilt unit DLL, and Display ActiveX control.

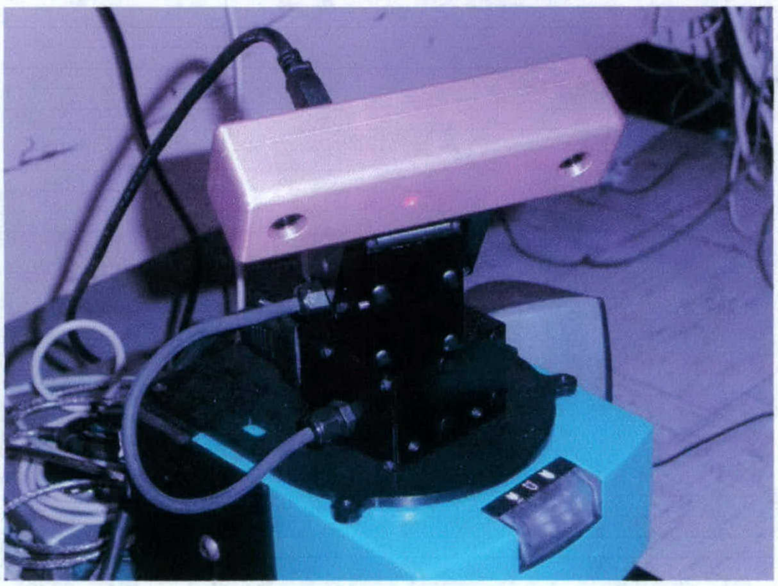

Figure 1: The Bumblebee stereo camera and the Directed Perception pan-tilt unit

A color-based object detection and recognition algorithm was implemented on this vision system. The robot detects three types of plastic bottles: Coke Cola, Mellow Yellow, and Aquifina. Visual servoing behavior to make the robot pick up the bottle was also implemented, including saccade and VOR (vestibulo-ocular reflex). A Sony or Canon pan-tilt-zoom video conference camera is mounted on the top or the front of some robots. A color-based bottle detection and visual servoing was implemented, and a picking-up-the-lying-bottle-using-the-arm behavior was accomplished using the vision system.

Multiple Robot Coordination
We have two different types of robots, Pioneer3 AT and Pioneer3 DX, each has different sensing and action capabilities. We explored multiple heterogeneous robot coordination using two different robots to implement a search-and-retrieve task. Figure 2 shows one robot, Pioneer3 watching another robot, DX, picking up a lying bottle from the floor. Pioneer3has a stereo camera mounted on a pan-tilt unit and a gripper. The gripper can grasp a standing bottle and carry it to the home position, however it cannot pick up a bottle if the bottle is lying on the floor. The other robot, DX, has an arm and a camera. The camera is mounted very close to the ground level due to mechanical constrains, and it can tilt up or down. The arm has 6 degrees-of-freedom (DOF), and each joint is driven by a hobby servo motor. These hobby servo motors are imprecise, and the servo motor controller only supports independent joint position control, i.e., coordinated joint movement is not possible. Thus, although one can use this arm to pick up a bottle that is lying on the floor, the picking-up movement sequence has to be pre-determined by experiments, and is performed with a fixed relative pose between the robot and the bottle. Also, one cannot use the arm to carry the bottle to the base because the servo motors are weak, instead, Pioneer3 is required to carry the bottle. Several visual servoing loops and coordination behaviors were implemented to accomplish this search-and-retrieve task.

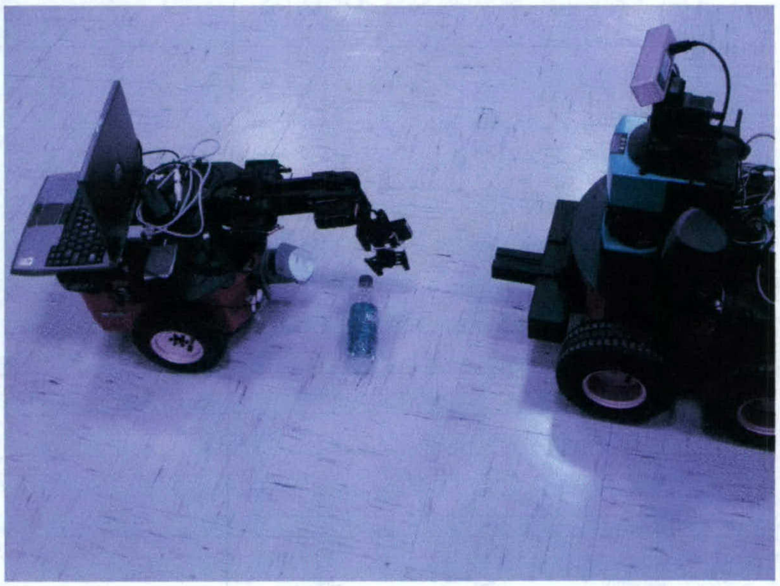

Figure 2: Two Pioneer 3 robots DX(left) and AT (right) cooperate to pick up a lying bottle

In our initial implementation, the subtask decomposition and allocation is pre-determined by the designer. The search-and-retrieve mission is carried out in the following fashion. First, both Pioneer3and DX robots stay at the home base. Given a map, Pioneer3was commanded to move into an area that contains different plastic bottles (Coke, Mellow Yellow, and Aquafina). Pioneer3 scans the environment and reports the direction of all the bottles that it has detected to the user. The user then commands the robot to retrieve a certain bottle, say Coke. Pioneer then moves close to the Coke bottle and detects the bottle's pose. If the bottle is standing on the floor, then Pioneer3aligns its gripper with

the bottle, grasps it, returns to the base following the path that it came in, and finally releases the bottle. The user then asks the robot to retrieve another bottle, say Aquafina. Pioneer3 moves back to the area and moves close to the Aquafina bottle because it memorizes the bottle's direction from last environment scanning. Again, it detects the bottle's pose. Suppose the bottle is lying on the floor and Pioneer3cannot pick it up. It then activates DX, and sends the bottle's pose information to DX. DX moves to a suitable location under Pioneer3s command, then picks up the bottle using the arm. Pioneer3then aligns its gripper with the bottle, grasp it, returns to the base, and finally releases the bottle.

Modeling Human-Robot Interaction

We implemented a human-robot interaction model on a Pioneer3 AT robot. This human-robot model has core functionalities that provide a robot with perception, awareness and social appropriateness. A multiple agent system was utilized, as shown in Figure 3. It includes Human Input Agent, Human Agent, Capability Agent, and a Human Database. The Human Agent gets input from a Human Input Agents and operates on a Human Database, and itself is composed of Monitoring Agent and Interaction Agent. The monitor agent monitors the environment for features or events that indicate that people are present or active. Currently the monitor can receive inputs from various detectors such as visual (face detection) or environmental (motion). The Interaction Agent coordinates the robot's role in the interaction. It processes input and the knowledge of the situation to determine the intention of the people in the environment and determine the appropriate response.

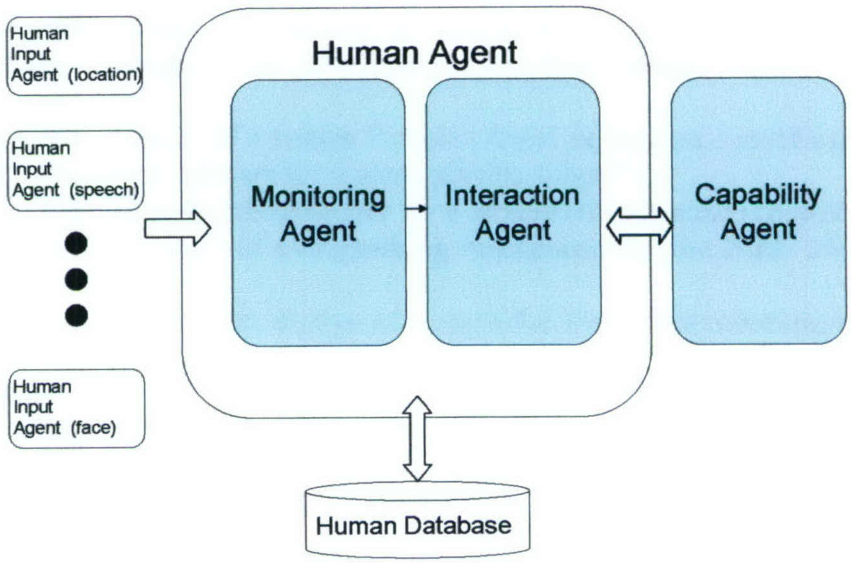

Figure 3: Architecture for human-robot interaction

The system has been implemented on a Pioneer 3 robot (cf. Figure 1 and 2), which has a stereo camera and a gripper. The context for our implementation is the interaction between a person and a robot that can perform helper tasks for the person. The robot

2. Basel Mohamoud, "Development of intelligent behaviors for multiple robots cooperative control."
3 Green Sheldon, "Rout planning and navigation with landmark recognition and localization.
4. Swapana Pelle, "Human guiding robot."

Currently we have robotics laboratory in electrical and mechanical engineering, and plans are to develop another laboratory in computer science department

Faculty Publications

Tamara E. Rogers, Jian Peng, and Saleh Zein-Sabatto, "Modeling human-robot interaction for intelligent mobile robotics", submitted to *14th IEEE International Workshop on Robot and Human Interactive Communication*, Nashville, TN, August 13-15, 2005

Jian Peng, Saleh Zein-Sabatto, and Ali Sekmen, "Implementing search-and-retrieve tasks by multiple heterogeneous robots", submitted to *IASTED International Conference on Robotics And Applications*, Cambridge, MA, October 31 - November 2 , 2005

Impact of Robots on undergraduate minority students in SEM

As a result of addition of new robots the interest of students has increased among electrical, mechanical and computer science students, and an interdisciplinary undergraduate research group in robotics is formed, hopefully it will lead to interdisciplinary research projects in robotics. The numbers of senior projects and masters theses have increased, and hopefully the research will generate Ph.D. dissertations.